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AUTHOR Iiyoshi, Toru; Hannafin, Michael J.
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ABSTRACT

This paper introduces and analyzes problems and issues in the design and use of cognitive tools in open, user-centered learning environments. It introduces a classification scheme for tool functions, and showcases several tools in a current educational hypermedia research and development effort. Information-seeking, information-presentation, knowledge-organization, knowledge-integration, and knowledge-generation tools are discussed, followed by a description of "The Human Body," an interactive CD-ROM based on the television series, "The Universe Within Human Body. The Human Body." Implications for future research and development in the design and use of cognitive tools in hypermedia learning environments are addressed. (Contains 18 references and 6 figures.) (Author/AEF)

Cognitive Tools and User-Centered Learning Environments: Rethinking Tools, Functions, and Applications

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Toru Iiyoshi
Knowledge Media Laboratory
The Carnegie Foundation for the Advancement of Teaching
United States
iiyoshi@carnegiefoundation.org

Michael J. Hannafin
Learning and Performance Support Laboratory
University of Georgia
United States
hannafin@coe.uga.edu

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Abstract: This paper introduces and analyzes problems and issues in the design and use of cognitive tools in open, user-centered learning environments, introduces a classification scheme for tool functions, and showcases several tools in a current educational hypermedia research and development effort. Implications for future research and development in the design and use of cognitive tools in hypermedia learning environments are addressed.

Background

Many hypermedia applications support open-ended, user-centered, interactive constructivistic learning environments (Hannafin & Land, 2000). In hypermedia, multimedia resources are linked dynamically in web-like form. Hyper-links emphasize expanding versus constraining the user's access to multimedia resources, thereby supporting a myriad of potential uses and learners. Hypermedia systems "open up" knowledge domains and support learners in exploring issues of unique interest and need (Hannafin & Land, 1997). Hypermedia systems can also facilitate construction via student-centered exploration, manipulation, and inquiry (Allen & Hoffman, 1991; Oliver & Hannafin, 2000).

Despite considerable interest and potential, however, "open" hypermedia systems present unique challenges to both designers and users. Due to the absence of explicit pedagogical support typical in direct instruction, users can become disoriented and overtaxed cognitively in open hypermedia learning systems (Roselli, 1991). A principal cause of disorientation and cognitive overload is the quantity of simultaneous, and largely undifferentiated, multimedia resources available. The learner is responsible for accessing, selecting, organizing, and analyzing information according to his or her unique needs (Jonassen & Grabinger, 1990; Land & Hannafin, 2000), but the systems provide little guidance. Learners are often ill-equipped cognitively to navigate vast multimedia networks and interpret their meanings.

The shift in pedagogical control to the individual involves providing more than resources of increasingly powerful multimedia images; it involves the deployment of well-reasoned strategic uses of *available* multimedia resources. The shift requires more than procedural assistance; it requires tools that scaffold the open-learning processes of diverse learners for varied purposes. The purpose of this paper is to describe and illustrate the functions of cognitive tools in hypermedia learning environments.

Cognitive Tools: Functions and Examples

Cognitive tools include both mental and computational devices that support, guide, and extend the cognitive processes of learners. They can amplify cognitive functioning and facilitate the creation of personal knowledge (Pea, 1985; Salomon, Perkins, & Globerson, 1991). Within hypermedia environments, cognitive tools enable learners to regulate the amount, sequence, and flow of available resources, make metacognitive judgments while navigating, and evaluate relevance (Park & Hannafin, 1993). Cognitive tools may also assist users in locating key information, recording or modifying available resources, connecting available resources, generating and linking personally relevant ideas with existing multimedia resources, and creating individual pathways that link the various multimedia resources contained in the system.

Tools are not inherently cognitive independent of the manner in which they are used. Their functions vary based upon the manner and context of their use (Jonassen & Carr, 2000). In some instances, a given tool might be used to collect information (e.g., text, illustrations) from a hypermedia learning environment; in others, the same tool might be used to organize relationships among various resources.

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Information-Seeking Tools

Information-seeking tools are especially important for open-ended hypermedia learning environments. Information-seeking tools extend the learners' ability to identify the availability of key information, locate it, and differentiate the nature of the information. Information-seeking includes recognizing and interpreting the problem, establishing a plan for searching, conducting the search, evaluating the results, and if necessary, repeating the process iteratively. Metacognition research suggests that the ability to reflect on actions while searching is critical to success during learning in open-ended environments (Duffy & Knuth, 1990). To enable learners to establish a plan of search, conduct the search, and evaluate the results, cognitive tools should help learners to monitor their information-seeking activities.

In practice, information-seeking activities are influenced by many learner attributes: prior domain knowledge, motivation, cognitive styles, familiarity with learning environments, and gender. Cognitive tools, therefore, support three interrelated seeking functions: locating, viewing, and retrieving relevant information.

Information-Presentation Tools

Information-presentation tools support learners as they attempt to understand the information they encounter. Such tools allow learners to access, then represent, information in varied ways. In open-ended hypermedia learning systems, users frequently encounter too much information. Consequently, they are often unable to identify or establish relationships among information. Thus, information presentation tools also need to help users to manage cognitive load (Oren, 1990).

Effective information-presentation tools extend three basic capabilities: 1) the ability to select relevant attributes and details while ignoring the irrelevant; 2) the ability to select information that enhances interpretation; and 3) the ability to provide alternative representations. The same information can be represented in a variety of forms, such as verbal statements, mathematical expressions, voice narration, tables, and illustrations. Appropriately represented information helps learners to act on their beliefs, construct higher-order relationships, and establish conceptual associations.

Knowledge-Organization Tools

Effective knowledge-organization tools enable learners to manipulate representations and relationships, promoting unique interpretations of, and relationships between, the information encountered. When learners attempt to organize vast amount of new information, they tend to oversimplify; the scope and complexity is often difficult to grasp. Accordingly, while some details may become well-organized, important relationships are often organized inappropriately or incompletely. Knowledge-organization tools, which allow learners to organize knowledge from various perspectives and dimensions, enable learners to establish key relationships among to-be-learned concepts.

Perhaps the most important function of knowledge-organization tools is the ability to tentatively structure (or restructure) information as it is encountered. This enables learners to construct working models of the domain under study. Knowledge-organization tools allow learners to manipulate information from various perspectives, helping them to organize concepts multi-dimensionally. To lessen cognitive load, knowledge-organization tools help learners to simplify organization and reduce *unnecessary* task complexity.

Knowledge-Integration Tools

Knowledge-integration tools support the connecting new with existing knowledge. One way to facilitate integration is to elaborate and upgrade one's mental model. Cognitive tools can facilitate conceptual understanding by supporting the testing of presumed relationships between newly organized knowledge and existing knowledge. Salomon (1993) suggested that computer tools may be especially useful in executing lower-level, tedious computational and graphic operations, allowing to the learner to focus on hypothesis generation.

Some cognitive activities may seem beyond the reach of users because assistance is unavailable to help establish connections between new information and existing knowledge. Knowledge-integration tools can help to bridge this gap. For example, *Sherlock I*, a computer-based environment for avionics troubleshooting, supports hypothesis testing by providing multiple paths for technicians to explore and coaching the technicians as they test their hypotheses (Lajoie, 1993). The hierarchical structure of the problem is modeled using a menu interface. Learners can constrain or expand problem parameters systematically as they test the limits of alternative hypotheses.

Knowledge-Generation Tools

The creation of unique learning artifacts is an important component in constructionist views of learning. Knowledge-generation tools help users to manipulate and generate unique interpretations and to represent newly generated knowledge flexibly and meaningfully. Allowing learners to represent newly generated knowledge, using different perspectives and modalities, is essential to deep understanding. *Handy*, a hypermedia editing tool, enables users to construct scenes and present them via computer (Nix, 1990). The user can generate and re-order scenes according to individual goals, interests, and needs. The scene can integrate source media such as videocode, audiotape, synthesized voice, digitized voice, animation, and graphics.

Cognitive Tools in Practice: *The Human Body*

The Human Body is an interactive CD-ROM based on the TV series, *The Universe Within Human Body*. *The Human Body* was designed and developed by instructional designers, TV producers, subject matter experts, teachers, and multimedia developers. This open-ended hypermedia environment contains approximately 1,000 individual multimedia-enhanced database screens featuring computer graphics, digital video, sound, and text that support learner-centered, constructivist learning in introductory anatomy and physiology (Iiyoshi & Kikue, 1995, 1996).

A variety of information-seeking tools are provided such as an alphabetical index, keyword search, hypertext and hyperpicture links, and concept maps. These tools enable learners to locate information they need from various perspectives; using their prior knowledge, conceptual relationship among text and pictorial information, and domain structure. For example, using the *Structure Map* tool illustrated in Figure 1, the learner can determine the availability of a concept using a hierarchically-structured map of each human body system. All components are displayed using both visual images and their corresponding names. The related information for each topic can be accessed by clicking the image or term of each concept. This tool provides a topical overview of related terms and concepts, as well as a means for accessing any or all of the terms and concepts.

Tools are also provided to support information selection and embedding into presentations. The *Bookmark* tool shown in Figure 2 allows the learner to "flag" key information they encounter, then subsequently access that information quickly and accurately. The learner can place a bookmark on any information screen, and generate a list of all selected screens. In effect, the cognitive load associated with ongoing review is managed by selecting screens for subsequent review.

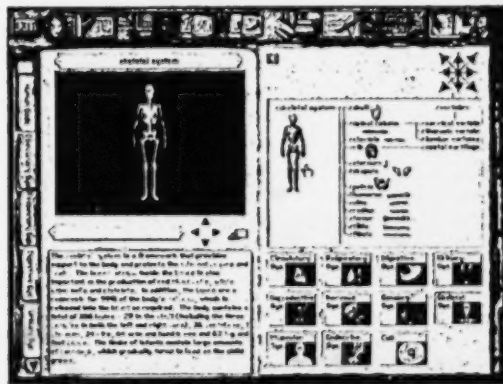


Figure 1: Structure Map

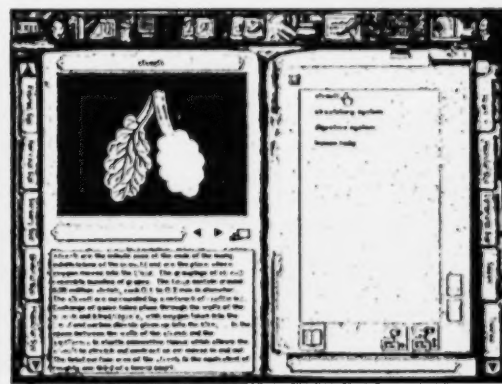


Figure 2: Bookmark

As previously noted, tools are not inherently cognitive; the context and nature of their use determine whether or not the tool augments, extends, or enhances the cognitive processes of users, and the manner in which such processes have been influenced. Stated differently, the same computer tool can support multiple cognitive processes. For instance, the previously described *Structure Map* presents a detailed concept map of each system also helps the learner to construct and elaborate the relationship between and among the systems and their components. Likewise, the *Bookmark* also enables learners to traverse selected information screens in user-customized ways.

The *Text Memo* tool, shown in Figure 3, also supports information organization. It allows the user to elaborate or annotate information contained in any information screen. When a learner writes a memo, the corresponding screen is automatically bookmarked. This electronic memo can then be linked to other information within the system. The tool aids not only in information organization, but also supports the development of user-specified, customized links.

To integrate newly organized information into pre-existing knowledge, metacognitive tools are provided. *Path Tracker* plays back all the information screens the learner went through since beginning study. This helps

learners to monitor what they have learned for better integration of their knowledge. Another example is *Reviewer* (Figure 4), which allows learners to monitor the information screens they examine. The ratio of the number of screens examined to the total screens in a particular component or a system is displayed. The tool is useful to identify the distribution of information they have looked through the system.

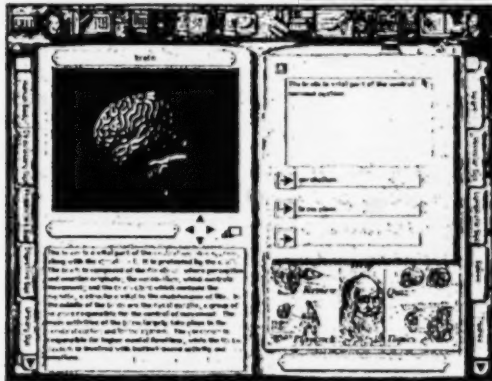


Figure 3: Text Memo

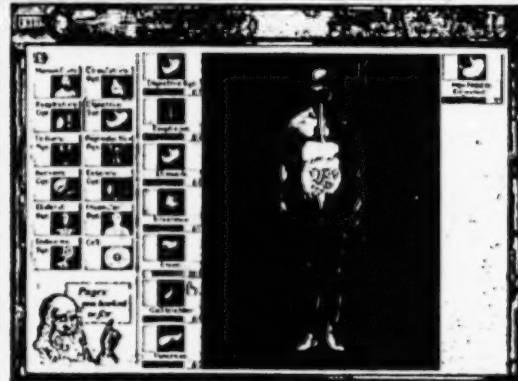


Figure 4: Reviewer

In addition, some tools aid learners in both integrating their knowledge as well as in generating new knowledge. The *Presentation Maker* enables learners to create individual collections, combining information screens and their personal comments. As shown in Figure 5, users can organize bookmarked and/or annotated resources via the *Text Memo* tool to indicate how the body reacted to create a personal affliction (e.g., heart attack of a family member). System contents are both modified according to unique experiences and integrated with the experiences of each individual user. In the presentation mode illustrated in Figure 6, each screen can be displayed according to the user's specifications.

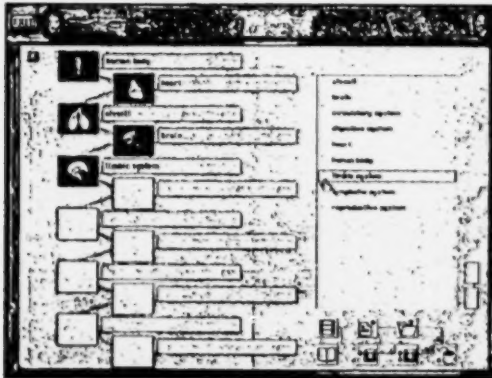


Figure 5: Presentation Maker (Authoring Mode)

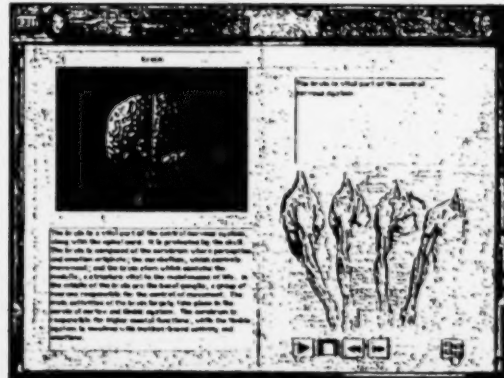


Figure 6: Presentation Maker (Presentation Mode)

Implications

Hypermedia systems provide open-ended environments for learner-centered, constructivistic learning. However, learners' cognitive resources are often overtaxed when exploring these vast information networks, limiting their ability to use the systems effectively. Although tools have supported cognitive processes in directed learning contexts, research is needed to better understand how they support processing in open-ended learning environments. Several significant research issues remain related to the design and use of cognitive tools.

Facilitation of Tool Use

Simply providing cognitive tools with open-ended hypermedia systems ensures neither usage nor success. We need to better understand how to facilitate the use of multiple tools; we also need to learn more about how creative users actually employ the tools we provide. Providing a variety of tools may be important to accommodate learners with different prior knowledge and tool-use skills. While it is evident that well-designed and implemented tools can facilitate, it is also apparent that tool use can hinder learning and performance. The cognitive load associated with tool use can actually increase rather than lessen the demands of the learning task. Individuals must often invest considerable cognitive resources learning how to use a tool; this problem becomes magnified as the number and variety of tool features increase. It is important to determine how tool use can be facilitated—both prior to as well as during use—to support user-centered learning.

Domain-Free Tools Versus Domain-Specialized Tools

The rapid growth in open hypermedia systems, such as the World Wide Web, suggests a paramount need for generalizable cognitive tools. However, such tools have rarely been developed much less validated. Increased attention to the design of generic cognitive tools, rooted in theory and research on human cognition and open-ended learning rather than particularized domain nuances, is needed. It may be possible to provide "meta tools" that help learners to construct and customize tools needed for a content domain, that is, to select and adapt from a suite of tools that are well-known and broadly applicable. While the widespread interest in tools that are uniquely crafted to support learning in particular domains has proven the viability and utility of cognitive tools, research on scalable tools is needed.

Evaluation of Tool Use

In order to examine how cognitive tools are used to support learners with open-ended hypermedia learning environments, close evaluation of actual tool use is critical. Several significant questions need to be addressed.

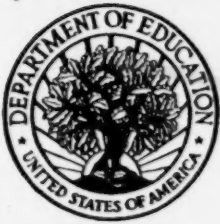
- (1) Are tools used as initially intended?
- (2) Do patterns of cognitive tools utilization exist?
- (3) How do individuals use multiple cognitive tools in their learning?

The proposed research is of significant potential consequence. Few researchers have immersed themselves in issues of design, and few designers are attuned to available research and theory. Tremendous interest has been generated in open learning environments, but little research and theory is available to guide or support the interest. We have taken large steps, but we may not be making needed progress. Neither the research nor the applied community has been, or will likely be able, to singularly advance the state of the art. Greater convergence of interest and expertise between theoreticians and practitioners is needed.

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